Room Temperature Sodium Ion Batteries

Jun Liu, Zhenguo (Gary) Yang, Yuliang Cao, Lifen Xiao, Wei Wang, Birgit Schwenzer

Presenter: Yuyan Shao

**Pacific Northwest National Laboratory,
Richland, WA 99252**

jun.liu@pnnl.gov

Acknowledgement:

**OE support for the technology.
OE program manager Dr. Imre Gyuk.
BES support for materials synthesis and characterization.**

Pacific Northwest
NATIONAL LABORATORY

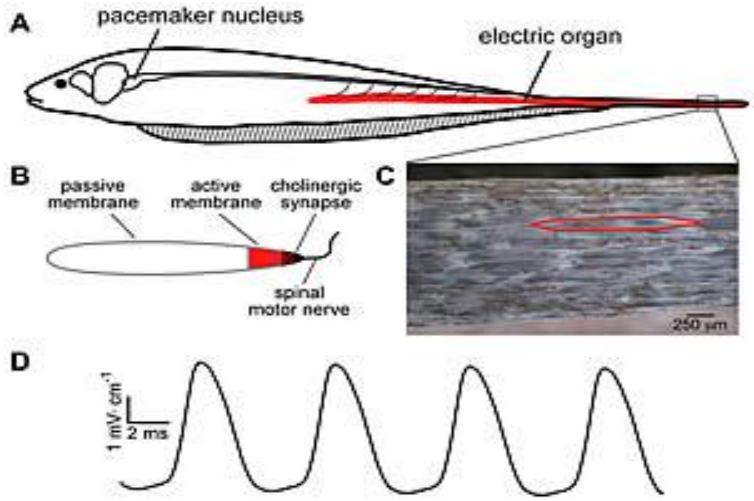
Disruptive technologies are needed for significant breakthrough in cost and performance

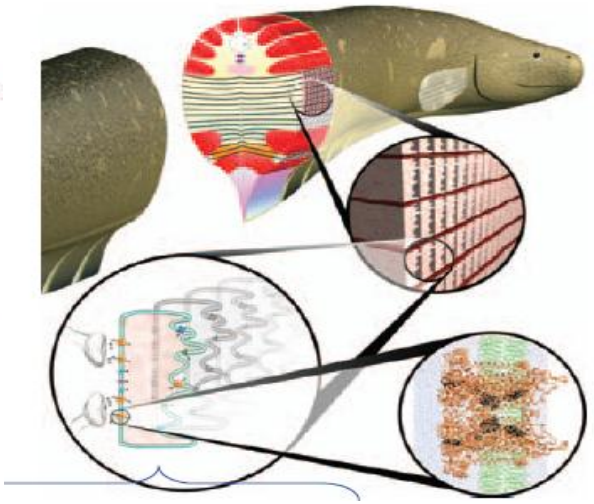
- Low temperature Na, Mg and Al batteries: Potentially very low cost and good energy density. Good electrode materials and electrolytes have not been developed.
- Pb-carbon: Potentially very low cost, long life, but technologies still need to be validated for real application.
- Li-S: High energy density. Limited power, poor cycle life due to polysulfide dissolution.
- Li-air (metal-air): Very high energy density. Poor reversibility and high risk.
- Hybrid systems (Li-flow battery, metal flow battery, metal-air flow battery, hybrid battery/supercap): Encouraging, potential low cost, high energy. In early stage of concept development.
- Molten metal battery: High energy density, high cost, high temperature, difficult to implement.

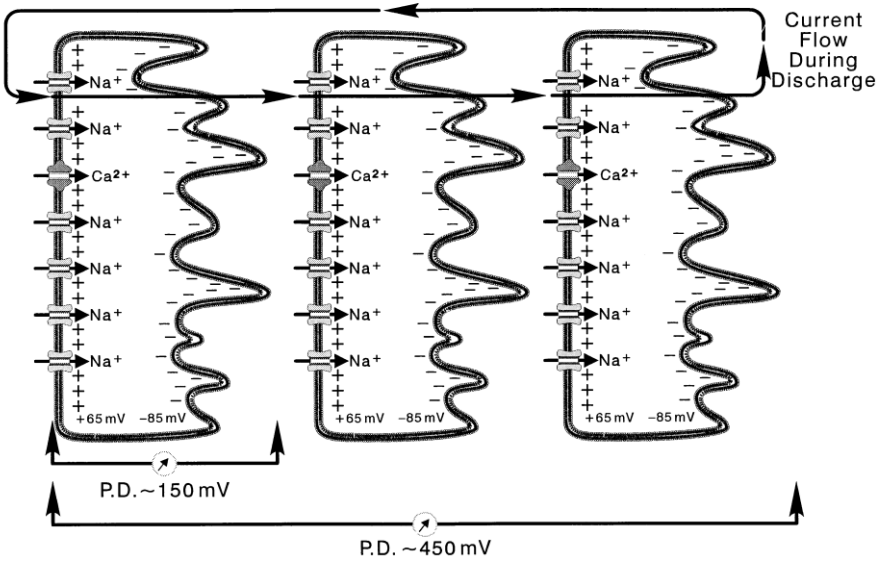
Pacific Northwest
NATIONAL LABORATORY

Can energy be stored with Na ions rather than Li ions?

Biology stores energy with Na, K, Ca ions, not Li ions (electrical eels).



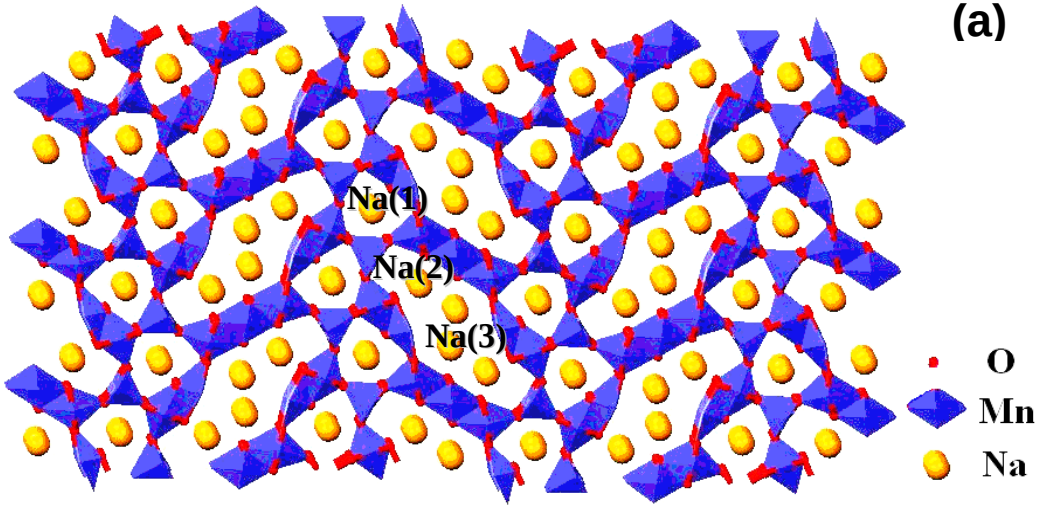




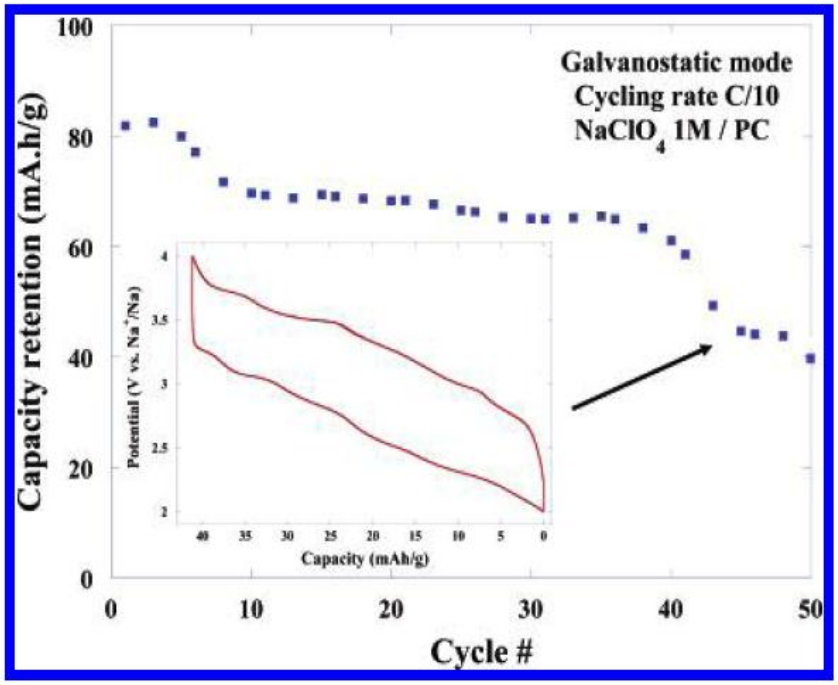
Storing large amount of energy using NaCl?

J. Xu, D. A. Lavan, *Nature Nanotechnology* ***2008, 3, 666.***

Concept of Na ion batteries has been around for some time



Schematic crystal structure of orthorhombic $Na_4Mn_9O_{18}$



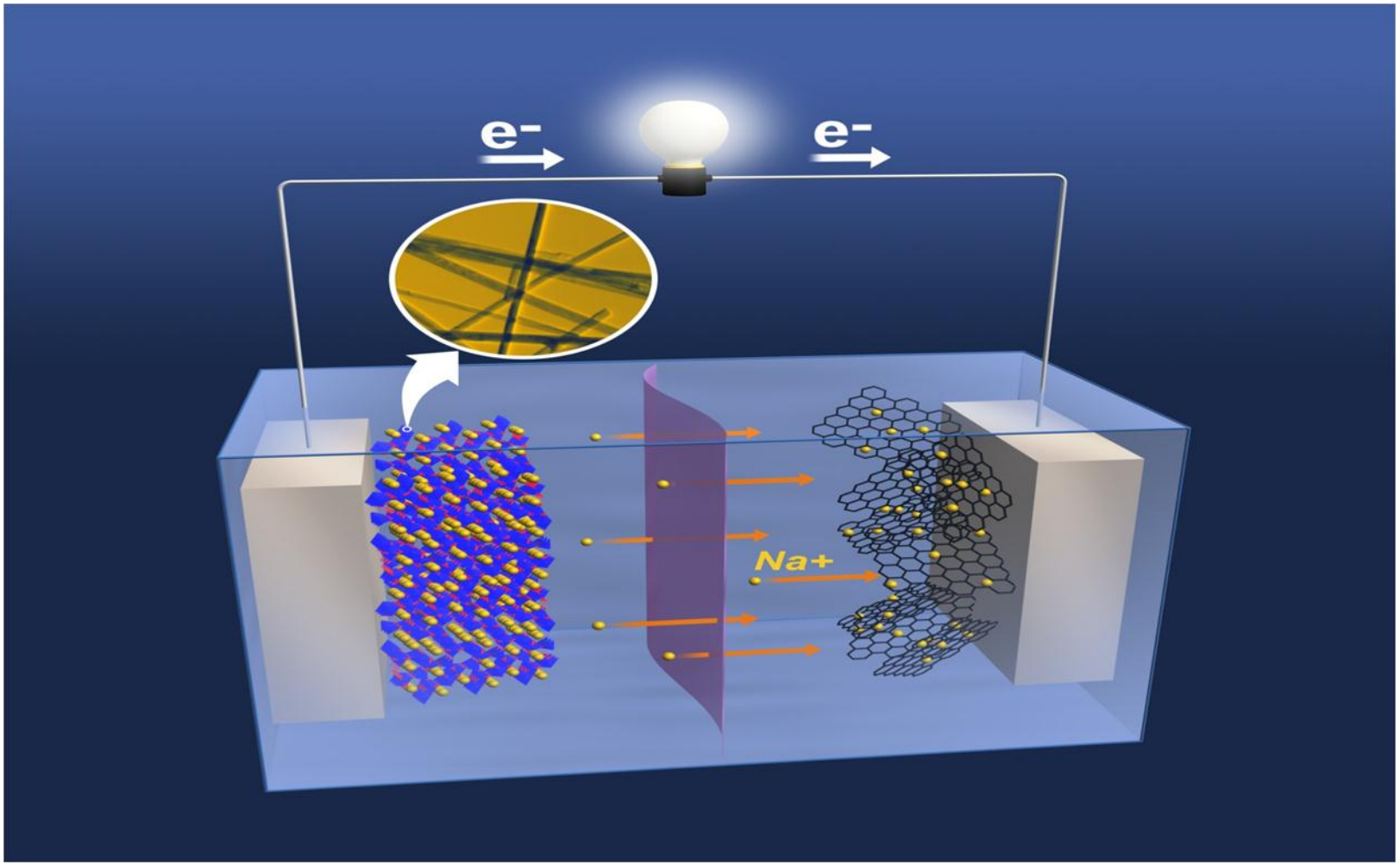
F. Sauvage, L. Laffont, J.-M. Tarascon, and E. Baudrin

Inorg. Chem. **2007**, *46*, 3289–3294

Na ion is much larger than Li ion and it is difficult to find good cathode and anode materials

Pacific Northwest NATIONAL LABORATORY

PNNL's nanowire based Na-ion batteries: demonstrated the feasibility of long life Na ion batteries

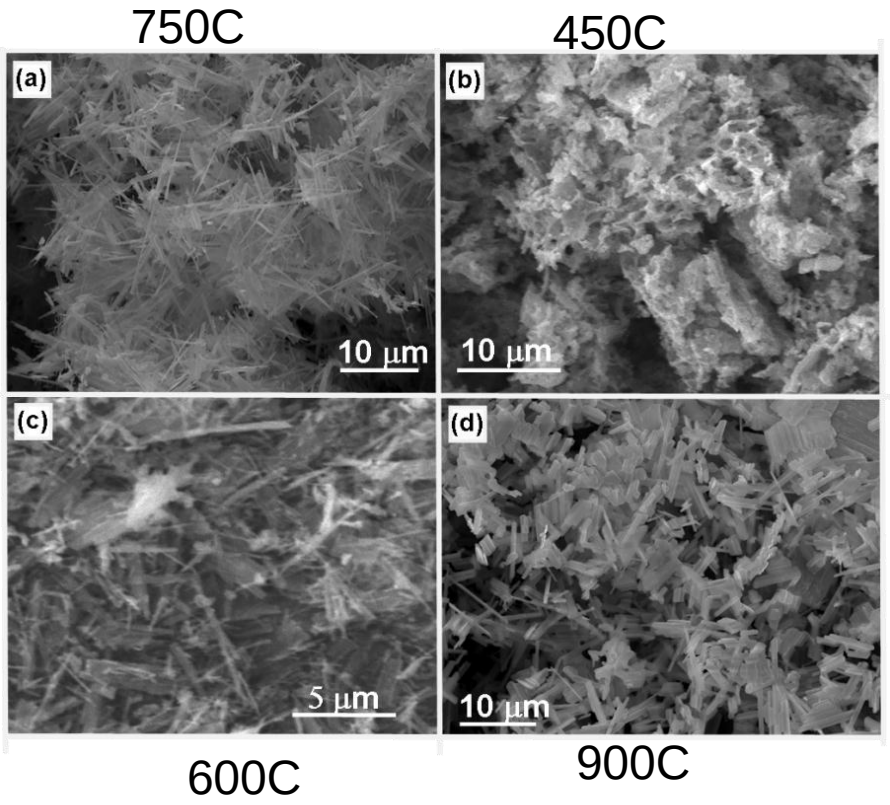


The performance of both single electrodes and full cells have been validated.

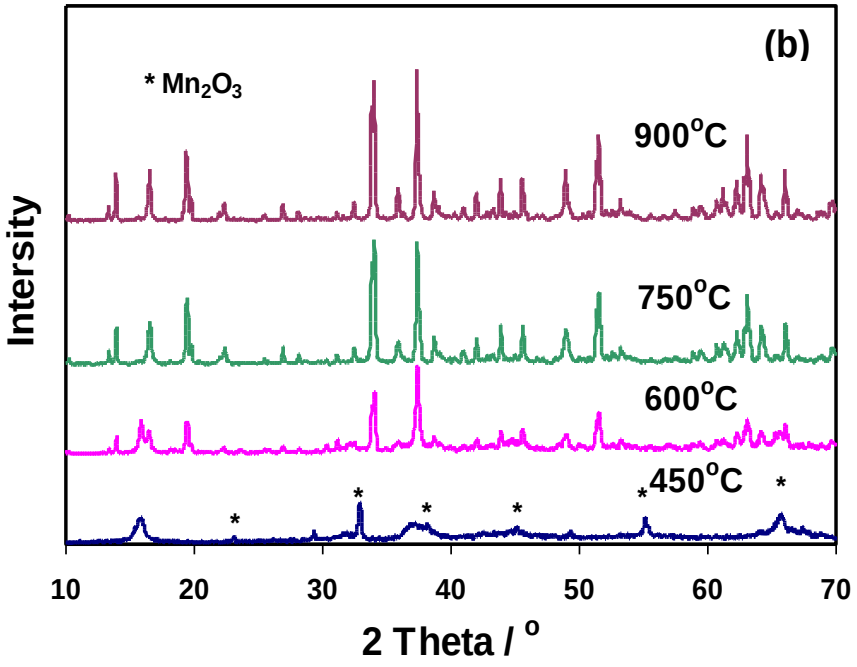
Y. Cao et al, Advanced Materials, 2011, PNNL work

Pacific Northwest
NATIONAL LABORATORY

Synthesis of single crystalline $Na_4Mn_9O_{18}$ nanowires as cathode using traditional processes and inexpensive chemicals

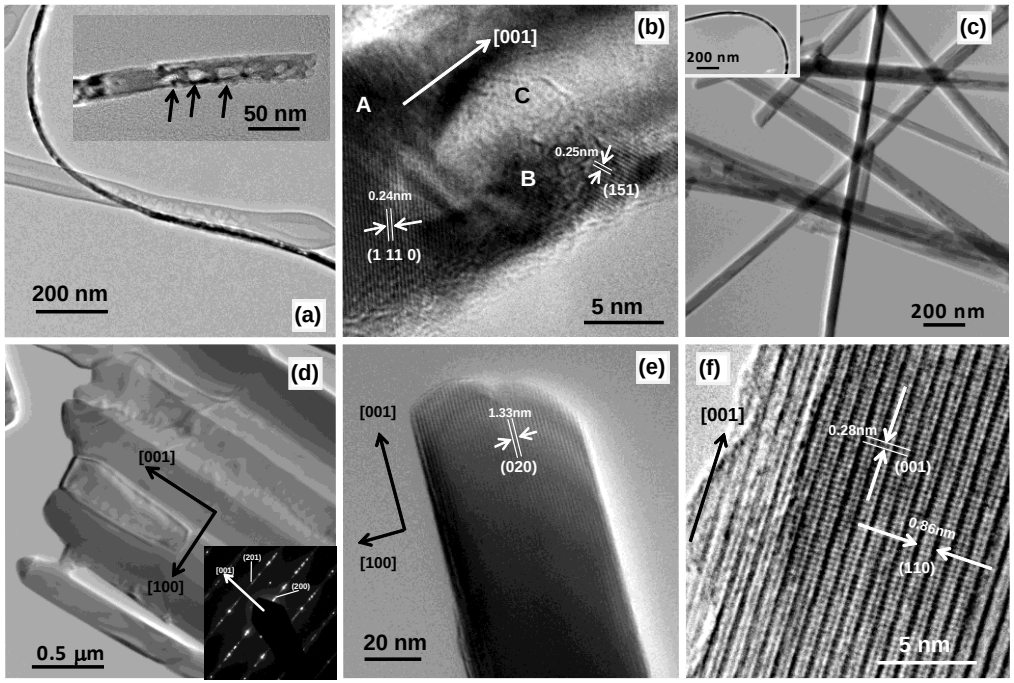


Optimization of the heat treatment temperature to achieve high crystallinity



Pacific Northwest NATIONAL LABORATORY

Small, high quality, single crystalline nanowires without lattice and structural defects are desired.

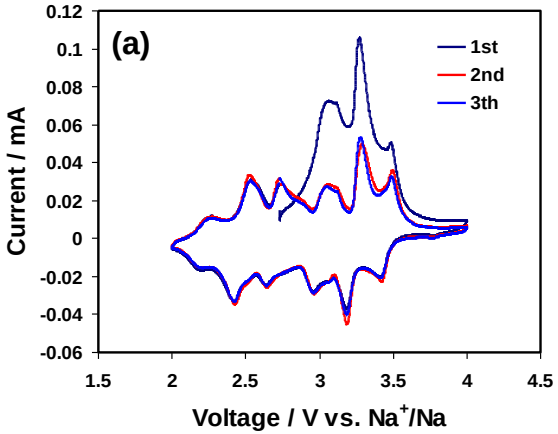


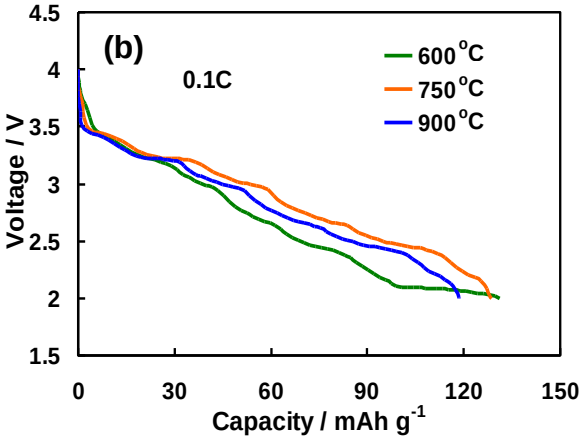
a, b: 600°C; c-f: 750°C

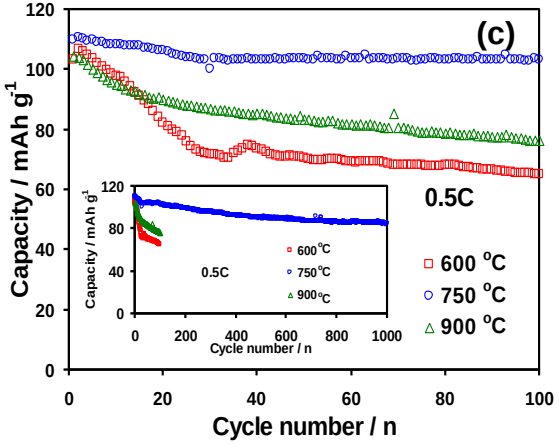
The single crystalline nanowires are formed from splitting plate-like structures. At a low temperature the nanowires contains voids and lattice defects. At high temperature the nanowires are fused together.

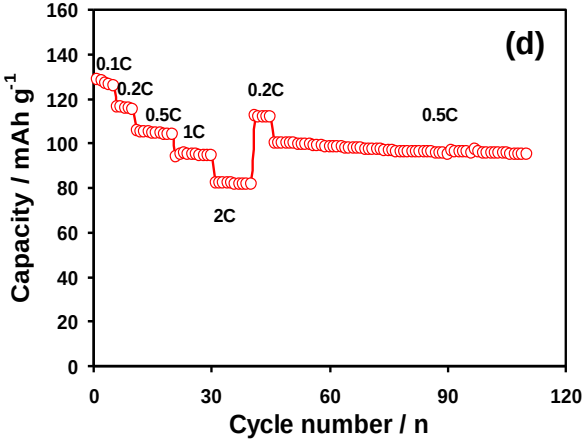
Pacific Northwest
NATIONAL LABORATORY

The nanowire based Na-ion battery have good capacity, long cycle life and good high rate performance.





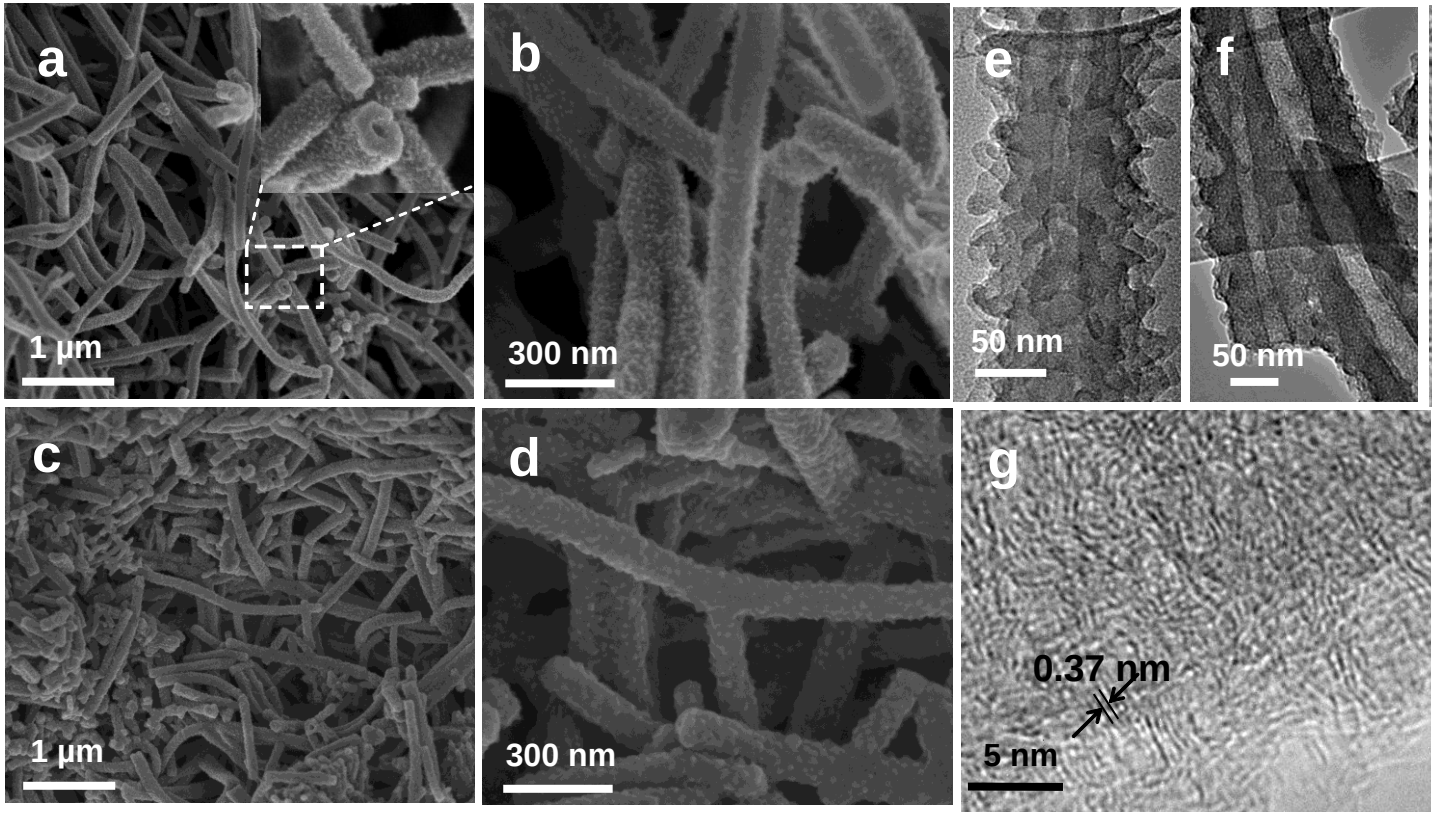




Pacific Northwest
NATIONAL LABORATORY

Synthesis of hard carbon nanotubes for anode applications

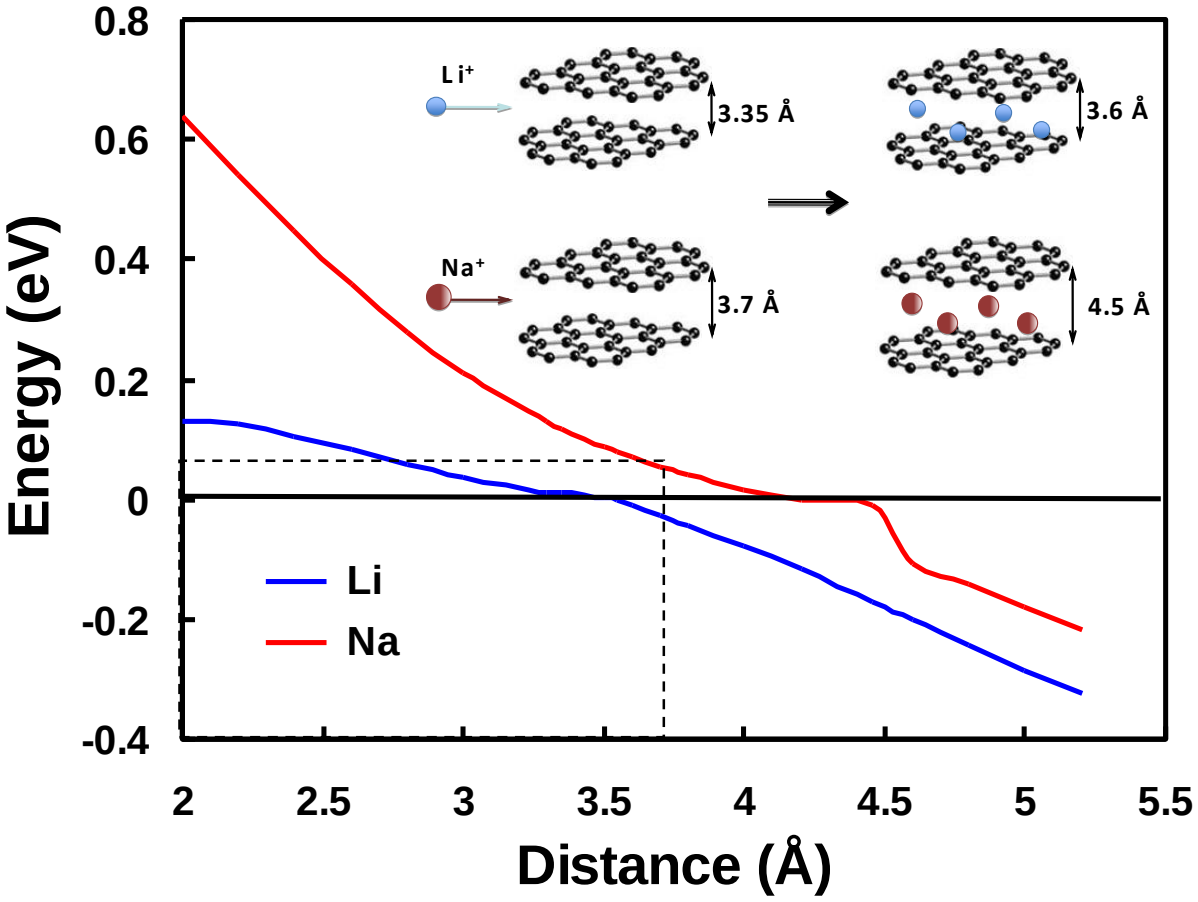
1st generation anode



The carbon has expanded spacing between the layers (0.37 nm)

Pacific Northwest
NATIONAL LABORATORY

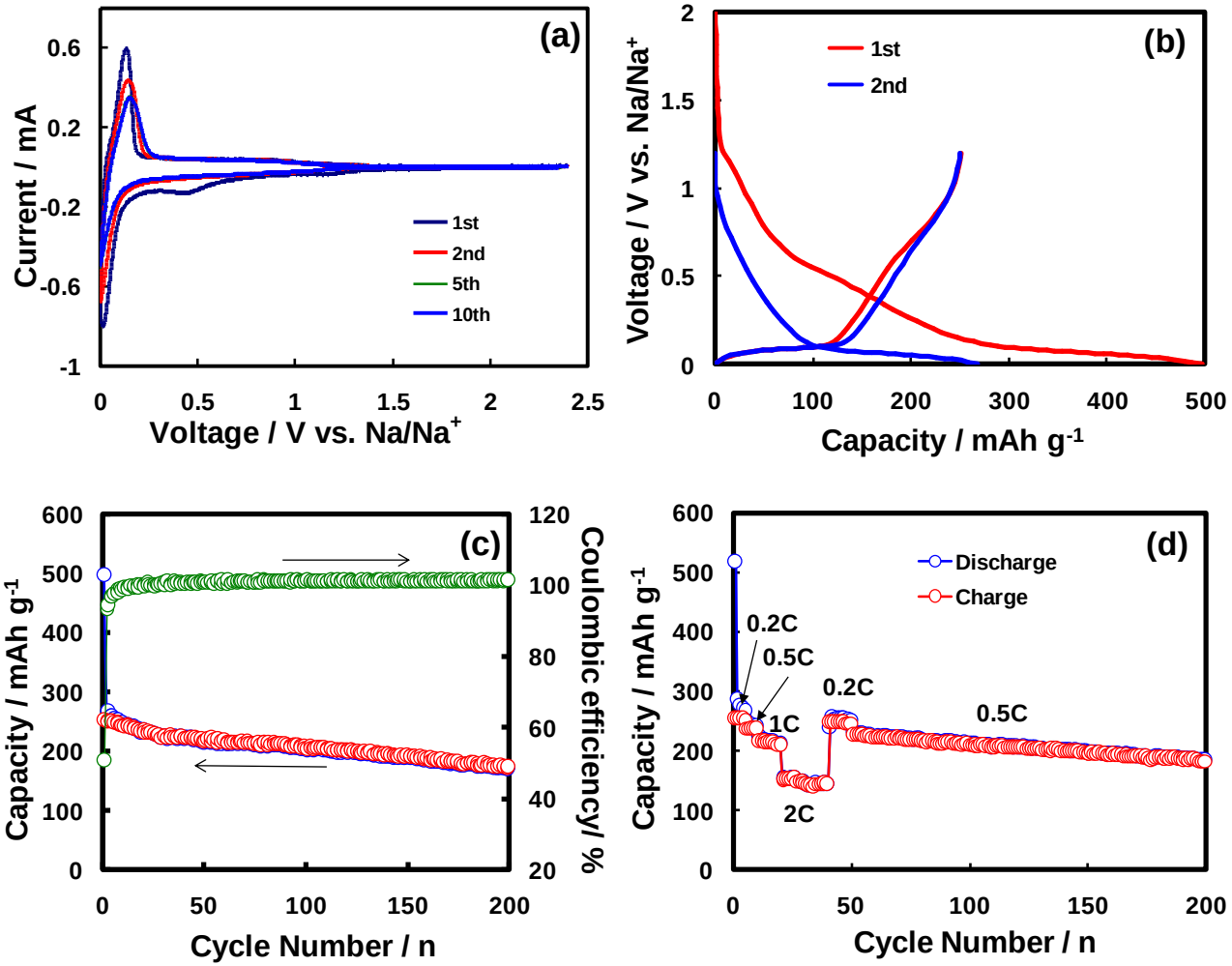
Theoretical calculation shows that Na ions can insert into carbon if the spacing is larger than 0.37 nm.



Na ion insertion is not possible if the spacing is less than 0.37 nm.

Pacific Northwest
NATIONAL LABORATORY

True, fast and reversible Na ion insertion in hard carbon nanotubes.



High capacity, good reversibility, and good rate performance is observed.

2nd generation electrode under development.

Pacific Northwest NATIONAL LABORATORY

Summary

Good cathode insertion materials based on single crystalline nanowires have been developed;

Good anode insertion materials based on hard carbon nanotubes have been developed;

Theoretical calculation was performed to determine the requirement for Na ion insertion;

High capacity, good reversibility, cycle life and rate performance have been demonstrated for both cathode and anode materials;

Full cell performance has been validated;

Second generation electrode development is already underway;

This project demonstrated the feasibility of long life room temperature Na ion batteries.

Pacific Northwest
NATIONAL LABORATORY